Using a Fuzzy Model to Evaluate Risks caused by Variation Orders in Construction Projects

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ABSTRACT

The construction industry is the main driving sector for any country's economy. However, it is too risky due to the many risks and challenges in this industry. One of the main challenges in construction projects is variation orders, as they lead to conflicts between project parties and cause poor project performance. This study aims to evaluate the risks associated with variation orders in construction projects using fuzzy risk assessment. The targeted population is the construction contractors in Palestine. A questionnaire survey was used to collect data on the severity and frequency of the 22 identified factors of variation orders. Then, a fuzzy logic system was developed to rate these factors. The factor risk level was determined by connecting the relationship between the severity and frequency indices using If-Then rules. The determination of risk level is a critical task in the proposed fuzzy system, which depends on the complex combinations of all If-Then rules. Risk is determined not only by the If-Then rules but also by the weight of each rule. This study shows that the factors with the highest risk levels are scope change by the client, client financial problems, unavailability of required materials, poor design documents, and modification of specifications. The results can serve as guidelines for project participants who need to prepare and implement a comprehensive and effective risk management plan to meet project goals. To improve project performance, construction parties are recommended to implement the proposed method to assess risks related to construction projects. Finally, the proposed risk model demonstrates the ability to evaluate risk levels by aggregating rules and combining the project risk factors using a fuzzy logic model and MATLAB.

Keywords-if-then; fuzzy logic; construction; variation; variation orders

I. INTRODUCTION

The construction industry is a major driving sector for any country's economy. However, it is too risky due to the many risks and challenges in this industry [1]. In [2], it was shown that risks in construction projects are unavoidable. Risks are available in all types of construction projects, such as residential buildings, commercial buildings, industrial projects, and infrastructure projects. Managing risks in construction projects is critical and complicated due to the many parties and challenges involved [3]. In [4], it was concluded that risks in construction projects prevent the achievement of project objectives in terms of cost, time, and quality. Previous studies reveal a common risk in construction projects, namely variation orders [1, 5-7].

Variation orders are simply defined as deviations from the project scope [1] and cause conflicts between different parties in construction projects that have a great impact on building projects. In [4], it was concluded that variation orders are the main sources of delay and cost increase in construction projects. According to construction parties, variation orders have a negative effect on project performance and cost [8]. Variation orders are a primary cause of time and cost overruns, negatively affecting project performance, profitability, and safety and potentially leading to project failure [9]. For instance, in [10] it was revealed that variation orders lead to a 5-10% increase in the cost of U.S. roadwork construction projects due to errors, omissions, scope changes, and unforeseen conditions. Meanwhile, a study in Nepal found that variation orders lead to time overruns ranging from 24.4% to 514.71% for more than 50% of projects [11].

Fuzzy theory [12] can be used to address data imprecision and uncertainty in construction projects. When risks are not well defined and are determined by subjective assessments rather than factual information, fuzzy theory offers a potentially useful method for calculating risk levels. It can be considered an effective method for handling unpredictable factors including severity and frequency. Therefore, fuzzy logic can be applied to several engineering tasks, including risk assessment, risk pricing, construction time delay, and the expected life of a building with various building components. Fuzzy logic provides a simple and effective technique for modeling risk assessment problems in case ranking risk is required [13].

The literature review revealed that very few or no studies have been conducted on using fuzzy models to establish the risk level for variation order factors in construction projects. This type of model has not been used in studying the factors of variation orders in construction projects, nor in studying many critical topics related to construction projects, such as delay and cost overruns, and labor productivity. This study aims to establish fuzzy models to investigate the risk levels of variation order-related factors in construction projects implemented in Palestine from the perspective of contractors. Construction professionals need to know that factors affect project outcomes, so they can take actions to improve project performance. The results of this study can help construction professionals, academics, and researchers understand the variation order factors and establish risk levels using fuzzy models.

II. PREVIOUS STUDIES

In [14], variation orders were defined as deviations from the scope clarified in the contract signed by the owner and the contractor. Variation orders have adverse effects on the performance of construction projects in terms of delay, cost increase, disputes, rework, and material waste [14, 15]. For instance, in [16], it was shown that variation orders account for 11% of cost increases in construction projects. In [16], the main factors influencing variation orders included specification updates and the lack of procedure and work manuals. In [3], the factors leading to variation orders in construction projects in Gaza were investigated, finding that the significant factors were design errors, late design changes, financial issues, poor experience in design and construction materials, poor communication, changes in specifications, and lack of materials and equipment. In the same area, in [17], it was found that design errors are a significant variation order-related factor.

In [8], it was shown that the owners are responsible for most of the changes in construction projects in Kuwait. This study also concluded that variation orders have a high impact on cost increase, and changes in plans are the most significant factor affecting variation orders. In [18], it was shown that the major severe factors contributing to variation orders in construction projects in Jordan were poor communication between participants, conflicts, plan changes, design mistakes, and poor contract documents. In [1], a direct relationship between variation orders and rework costs was found in public construction projects. This study also showed that the critical factors for variation orders were unclear scope, poor coordination between designers, financial difficulties, design mistakes, and material replacements. In [19], a fuzzy risk assessment method was proposed to rate the influence of cost overrun factors in international construction projects. In [20], a comprehensive risk evaluation approach was presented, which used fuzzy logic to assess the influence of risk factors. This study also offered a decision support tool that can be used when making bid decisions for international construction projects that involve risk.

In [4], the main factors of the variation orders in construction projects in Saudi Arabia were examined through a questionnaire survey. This study considered 32 factors, finding that the critical were additions, design errors, poor coordination between parties, poor labor skills, financial problems, and poor construction methods. In [7], it was found that the main factors affecting variation orders during the construction phase are payment delays, design changes, unclear scope, lack of experience, design mistakes, and specification changes. In [21], a study of the causes of variation orders in Oman construction projects showed that modification of specifications, changes in design and blueprints, and time gaps in the execution of the project were the main sources of variation orders. In [22], the causes of variation orders in construction projects in Saudi Arabia were investigated, identifying 21 factors using a questionnaire survey to collect the data from targeted construction parties. The results showed that design changes and payment delays were among the main factors related to variation orders. In [23], it was shown that owners are responsible for construction variation orders in the U.S. followed by consultants and contractors, respectively. This study showed that owner's design modifications and scope change, ambiguous site conditions, mistakes and omissions in design, poorly defined drawings, adjustment of the timeframe of projects by the owner, lack of management practices by contractors, inconsistency between contract documents, and poor estimate of cost and weather conditions were the main sources of variation orders. Moreover, many control measures were examined. The study stated that collaboration between construction parties, such as checking the contract documents in a way that all gray areas are clarified in the preconstruction phase, is considered an effective practice. Besides, using technologies such as BIM in all project stages is deemed efficient in managing variation orders. In [24], a fuzzy model was developed for bid/non-bid decision-making in construction projects. This model is an example application of the fuzzy approach in construction projects. However, in [25], it was stated that using fuzzy logic in construction risk management is limited. One of the main aims of this research was to use fuzzy logic to rate the risks of variation orders in construction projects.

III. STUDY OBJECTIVES

The main objective of this study are:

- Determine the risk weights for each factor using an assessment model and evaluate the risk performance based on a fuzzy logic model using MATLAB software rather than relying on questionnaires as in previous works.
- Design a flexible assessment model to evaluate risks using fuzzy logic. Therefore, this research aims to develop a decision-support tool for a construction project based on fuzzy logic, considering all factors' risk severity and frequency.
- The results of the fuzzy logic risk performance analysis tool are employed to determine the project's logical risk contingency.

IV. RESEARCH METHOD

After setting the study objectives, the following procedure was followed to achieve them:

- Factors that might affect design variation orders are identified from previously published articles. Twenty-two (22) variation order-related factors were identified and tabulated in a questionnaire form. A questionnaire survey was used to achieve the objectives since it is a good tool in this regard [26].
- The questionnaire includes two sections: Section 1 collects information about the participant, such as experience, position, size of company, etc., and Section 2 includes the list of variation order-related factors. The respondents were asked to identify the severity and frequency of each factor using a 5-point Likert scale. The scale ranged from 1 (very low severity) to 5 (very high severity). The same scale was used to identify the frequency from 1 (very low frequency) to 5 (very high frequency).
- The questionnaire was sent to three experts to examine the suitability and validity of the questions. Slight changes were suggested.
- The questionnaire was then distributed and collected from the targeted participants. Different methods were used in distribution and collection, such as email, fax, face-to-face, and Google Docs.
- After collecting the questionnaire, SPSS was used to analyze the data. The analysis included the average score and standard deviation. The Severity Index (SI) and Frequency Index (FI) were calculated using the mean value of the responses.
- A fuzzy logic system was used to assess risk and develop a tool to implement the proposed method. The procedure for fuzzy risk mapping was as follows:
  - The inputs and outputs of the system were defined. The membership function was selected for each input and output. A membership function is a curve that indicates how the value of a fuzzy variable corresponds to a degree of membership on a scale from 0 to 1. The term "membership functions" in this article refers to how much a fuzzy risk map belongs to various sets that are described by linguistic terms such as green risk, yellow risk, and red risk.
  - The risk map is described using If-Then rules, which connect current knowledge and experiences to create correlations between risk and input variables. The aggregation rules illustrate the various scenarios in which the risk map is altered. The If-Then rules display the level of risk map when the values of input variables (severity and frequency) are represented using different linguistic terms.
- Perform fuzzy operations to combine fuzzy rules into a fuzzy risk map, after which the risk is assessed using various input variable values.

This procedure was executed using the Matlab fuzzy tool. Figure 1 depicts the Fuzzy Inference System (FIS) that consists of two input variables (severity and frequency) with five membership functions for each and an output variable (risk map) with three membership functions, which is described using 27 If-Then rules.

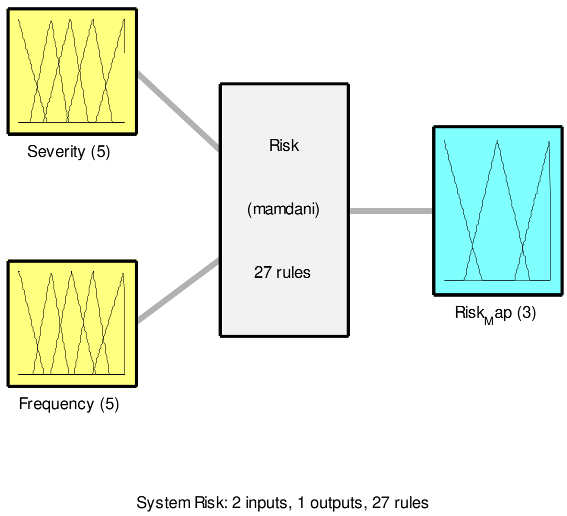

Fig. 1. Fuzzy Inference System (FIS) [12].

A. Study Population

The study population includes registered contractors of the Palestinian Engineers Association. The population was selected randomly from an available list in the association. The registered population was 190 contractors of grades 1 and 2. The representative sample of the population was calculated using (1) [27]. Table I shows the results. When n and $n-1$ are close to each other, the calculation should be stopped.

$$n = \frac{\left(t \times \frac{s}{d}\right)^2}{\left\{1+\left(t \times \frac{s}{d}\right)^2\right\}/N} \quad (1)$$

where n is the representative sample size, N is the registered population, t is the normal curve abscissa cuts area of $\alpha = 0.01$ at the tails, d is the estimate error ($d = 0.01$), and s is the maximum standard deviation.

TABLE I. COMPUTATION OF REPRESENTATIVE SAMPLE

	Contractors
n_0	190
n_1	88
n_2	57
n_3	43
n_4	35
n_5	29
n_6	24
n_7	19

According to Table I, the representative sample is 19 contractors. The questionnaire was sent to 50 contractors. Forty-two (42) contractors filled out the questionnaire and returned it (86% response rate). More than 60% of the respondents had experience of more than 10 years in construction projects. Table II shows the respondents' positions.

TABLE II. RESPONDENTS' TITLES

Respondents title	%
Project manager	10%
Construction manager	13%
Office engineer	28%
Site engineer	21%
Project engineer	24%
Other	4%

B. Implementing the System Using Fuzzy Logic

Depending on the frequency and severity indices for each factor, a risk level was established (Table III), and each factor zone was identified on the risk map (Table IV). Accordingly, the factor risk level was determined by connecting the relationship between the severity and frequency indices using If-Then rules. The determination of risk level is a critical task in the proposed fuzzy system, depending on the complex combinations of all If-Then rules. The Fuzzy Logic Toolbox in MATLAB allows for the implementation of two forms of FIS: Mamdani-type and Sugeno-type. The most widely used fuzzy approach is Mamdani's fuzzy inference method

TABLE III. SCALE USED TO IDENTIFY FACTOR'S SEVERITY AND FREQUENCY LEVEL [28]

Index value (scale)	Severity	Frequency
≤ 20%	Very Low (VL)	Very Low (VL)
20% - 40%	Low (L)	Low (L)
40% - 60%	Moderate (M)	Moderate (M)
60% - 80%	High (H)	High (H)
80% - 100%	Very High (VH)	Very High (VH)

TABLE IV. SCALE USED TO IDENTIFY FACTOR'S SEVERITY AND FREQUENCY LEVEL [28]

Severity / Frequency	VL	L	M	H	VH
VL	Green	Green	Green	Yellow	Red
L	Green	Green	Yellow	Red	Red
M	Green	Green	Yellow	Red	Red
H	Green	Yellow	Red	Red	Red
VH	Green	Yellow	Red	Red	Red

1) The FIS Editor

The high-level issues regarding the number and names of input and output variables are handled by the FIS Editor, displaying a fuzzy inference system's generic information.

2) The Membership Function

Figures 2-4 display the membership functions used for the input and output variables. A fuzzy number's shape and a linguistic term's scale must be chosen based on the requirements and experiences of the user. For this application, the triangle shape, which is frequently used for membership functions, was deemed appropriate [15]. Furthermore, the definition of linguistic variable states is Very-Low (VL), Low (L), Moderate (M), Very-High (VH), and High (H) for both input variables, as shown in Figures 2-3. Figure 4 shows that the output variable (risk map) is classified into three predefined classes (Green, Yellow, and Red) after a risk score is assigned to a risk factor using a 0-1 scale.

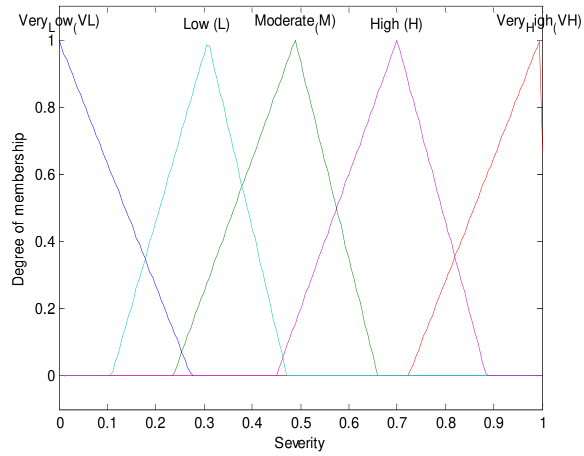

Fig. 2. Severity membership function

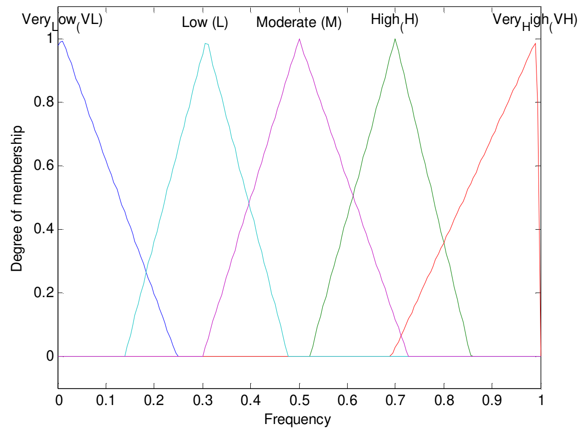

Fig. 3. Frequency membership function.

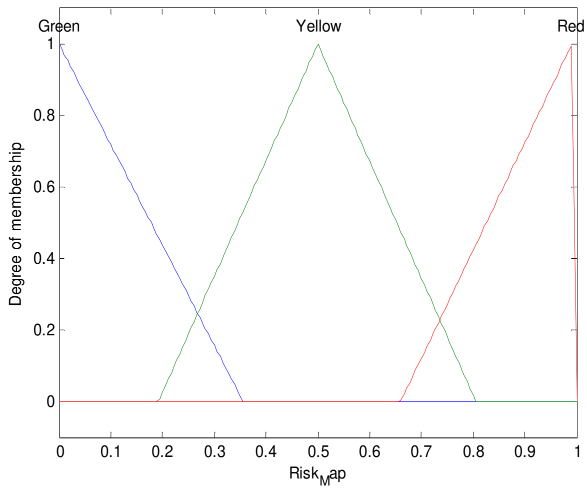

Fig. 4. Risk-map membership function.

3) The Rule Viewer and Surface Viewer

In the risk assessment phase, the proposed model establishes aggregation rules and prepares related decision matrices as a result of the questionnaire analysis. Aggregation rules form the basis for fuzzy operations and control actions. The rules for FIS were built from Table III. To simplify the process, the If-Then rule in the Rule Editor was used to represent variables, which were treated as independent of each other, as shown in Figure 5. The rule viewer displays a roadmap of the entire fuzzy inference process. The figure shows 27 tiny plots, as shown in Figure 6. Finally, Figure 7 shows the 3D surface viewer produced by the FIS, using any combination value of the severity and frequency perceptions in the input variables to predict the risk output. The 3D surface viewer is compatible with Table III risk levels. 3D surface Viewer maintains the homogeneity with If-Then rules.

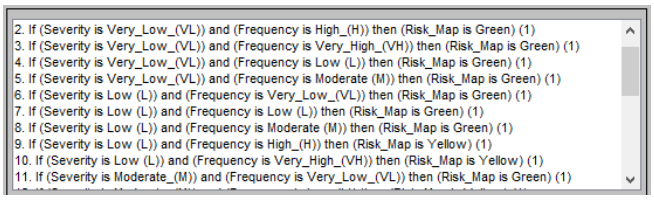

Fig. 5. If-Then rules.

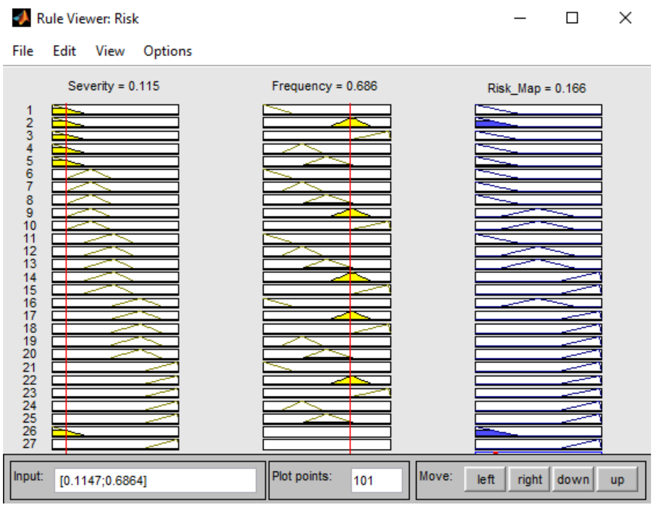

Fig. 6. Rule viewer for FIS.

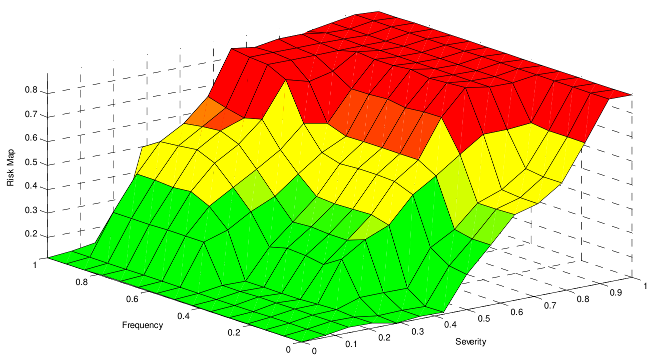

Fig. 7. 3D surface viewer of the risk map.

V. RESULTS AND DISCUSSION

A. Fuzzy Model Verification

Various values of input variables were chosen to verify the fuzzy system. Using Matlab function evalfis, a holistic evaluation is provided in Table V to cover all risk levels. As an example, in evalfis([0.9 0.5], Risk), 0.9 is the value of severity and 0.5 is the value of frequency. In the example provided, using an appropriate combination of the If-Then rules for severity and frequency, the risk level is estimated as 0.8728, which is a red risk level. Using the membership function given in Figures 3-4 and the de-fuzzification technique, different values are found in Table V.

TABLE V. FUZZY RULES FOR PREDICTING RISK LEVELS

Severity /Frequency	**0.10**	**0.30**	**0.50**	**0.70**	**0.90**
0.10	0.1275 G	0.128 G	0.2834 G	0.4991 Y	0.8728 R
0.30	0.129 G	0.2790 G	0.5477 Y	0.8830 R	0.8728 R
0.50	0.129 G	0.2788 G	0.5477 Y	0.8833 R	0.8728 R
0.70	0.129 G	0.5297 Y	0.7759 R	0.8833 R	0.8728 R
.090	0.129 G	0.5640 Y	0.8748 R	0.8748 R	0.8728 R

B. Risk Map for Variation Order-Related Factors in Construction Projects

Table VI shows the risk levels of variation order-related factors. Twenty-two (22) related factors were identified from previous published studies and input from local construction experts. Participants were asked to rank the severity and frequency of these factors using a 5-point Likert scale. The severity and frequency indices were calculated based on the responses of the participants. Accordingly, the factor risk level was determined by connecting the relationship between severity and frequency indices using the If-Then rules. Determining the risk level is a critical task, which depends on the complex combinations of all If-Then rules. Risk is determined not only by the If-Then rules but also by the weight of each rule. The results show that the variation order factors that had the highest five risk levels were scope change by the client, client financial problems, unavailability of required materials, poor design documents, and specification modifications.

The scope change by the client ranked at position 1, being the main factor affecting variation orders in construction projects. A well-defined scope in the early stages ensures smooth performance and progress of the project. An unclear scope in the early stages leads to many late changes in specifications, design, material, and construction methods. This result is supported by [1, 14, 17]. Client financial problems ranked in position 2. Financial difficulties of the client lead to omissions, design and specification changes, and changes in scope. This result was also concluded in [3]. Unavailable required materials ranked at position 3 as a critical contributor to variation orders in new construction projects. The unavailability of materials in the Palestinian market could be due to limitations on imported materials by the Israeli authorities or high taxes on imported materials. This situation leads to changes in the specifications and materials. Therefore, the designer should be familiar with the materials available in the local market to recommend them to the client. This would reduce changes during construction. This result was also found in [1, 3]. Poor design documents are ranked at position 4 as a top critical variation order factor. Well-prepared design documents are very important for the contractor to understand the requirements, specifications, and scope of the project. Unclear design documents lead to misunderstandings between parties and disputes during construction. This result was not mentioned in any of the previous studies investigated. Specification modifications conclude the top five variation order factors. There is a link between this factor and the other top variation order factors, as it might be a result of unclear scope, unavailable required materials, and financial problems. This result is in agreement with [3].

TABLE VI. RISK LEVEL FOR VARIATION ORDER-RELATED FACTORS IN CONSTRUCTION PROJECTS

Factor	SI	FI	Risk level
Scope change by client	70	49.6	88.32
Client financial problems	73.2	64.2	87.41
Required materials are not available	76.2	64.8	87.36
Poor design documents	72	63.2	87.12
Specifications modification	71	62.2	86.81
Inflation in the construction industry	70.4	61.2	86.48
Poor coordination between participants	64.8	60	78.36
Poor financial capability of the contractor	63.8	57.8	74.97
Poor site investigation before the design stage	63	53	72.98
Additions and omissions	61	53.8	67.85
Lack of contractor's experience	60.6	53.2	67.05
Fluctuations in construction material price	60.4	55.8	66.68
Lack of qualified labors	59.6	46.2	65.31
Lack of required equipment	59	48.6	64.38
Misunderstanding of contract documents	59	49	64.38
Mistakes by labors	58.8	48.4	64.09
Conflict between parties	59	61.2	63.63
Design change by client	57.8	62	62.86
Poor contractor's qualifications	57.8	51.2	62.73
Project complexity	53.8	50.6	58.39
Ground conditions	52.6	48.4	57.25
Weather	49.4	41	55.12

VI. CONCLUSION

Fuzzy risk map evaluation offers a promising method for quantifying risk assessments when the risks are not well-defined and are instead determined by the subjective evaluation of certain facts. This study presented an approach for the construction project risk map using fuzzy model components. The applicability of the proposed method was evaluated in real scenarios. The main contribution of this study is modeling risk management in the field of construction management using FIS, as well as creating a method for risk assessment based on the suggested risk model. With this method, assessments can use language-based terminology rather than actual numerical data to make decisions. Since linguistic terms are not mathematically expressed, to cope with difficulty, each one is assigned a trapezoidal fuzzy number that corresponds to its meaning, which embodies each verbal term. This is instead of depending on questionnaires in previous works. Another possible benefit is that it improves the managers' experience by simply adding more If-Then rules and uploading them to the system. This might help in the creation of a corporate risk memory.

This procedure was implemented in construction projects in Palestine to identify risk levels for factors related to variation orders. Twenty-two (22) factors were identified from previous studies and opinions of local construction experts. A questionnaire survey was used to collect responses from the targeted contractors. The results show that the top five critical variation order-related factors are scope change by the client, client financial problems, unavailability of required materials, poor design documents, and specification modifications. The results can serve as guidelines for project participants who need to prepare and implement a comprehensive and effective risk management plan in a way that meets the project's goals. To improve project performance, construction parties are recommended to consider these critical factors in all project phases to reduce risks and help achieve project success.

VII. FUTURE WORK

As Artificial Intelligence (AI) opens new windows for molding, ranking, and classification of risk problems, neural networks and other AI methods can be used to model risks in construction projects. Consequently, a comparison study can examine and select the best tool based on various AI models.

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